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The influence of temporal scale selection on pelagic habitat biodiversity indicators

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Abstract

The development of biodiversity indicators is an integral component of forming marine strategies under the European Marine Strategy Framework Directive (MSFD). A key stage in the development of biodiversity indicators is the selection of an appropriate temporal scale over which to assess change in indicator state. This presents a particular challenge for the development of plankton indicators for assessing the state of pelagic habitats, due to the inherent stochasticity of plankton dynamics and the sensitivity of indicators to both climate-driven change and directly manageable pressures. Using two plankton indicator metrics, we demonstrate that the outcome of indicator assessments is inherently influenced by the temporal scale of the time-period over which the indicators are assessed. For example, we show that the inclusion of data from before a regime shift that occurred in the 1980s often alters the assessment of change compared to only including data from after the regime shift. We highlight that ultimately the appropriate temporal scale selected depends on the policy questions being addressed. We also suggest that reporting indicators over multiple temporal scales within an assessment helps provide information relevant to contemporary management, whilst also retaining crucial multi-decadal trends such as those caused by climate change.

1 Introduction

Monitoring of marine biodiversity underpins the achievement of healthy marine ecosystems by ensuring that management can be flexible, adaptive and effective (Addison et al., 2017). Across European seas, cumulative pressures from human activities are causing changes in marine biodiversity that are being addressed through both national and regional scale management frameworks (Apitz et al., 2006; Berg et al., 2015). Focusing at a regional scale, the European Union (EU) Marine Strategy Framework Directive (MSFD) incorporates biodiversity status into ecosystem-based management strategies, where different components of the marine ecosystem are formally monitored and assessed against targets representing 'Good Environmental Status' (GES) (Directive 2008/56/EC). As the base of the marine pelagic food web, plankton communities form one of the key components of these biodiversity assessments, and plankton community indicators are used to assess the status of 'pelagic habitats'.

A suite of indicators for pelagic habitat biodiversity has been identified and developed for formal assessment under the MSFD, reflecting change in bulk, functional, and compositional aspects of plankton community structure and ultimately, pelagic habitat state (McQuatters-Gollop et al., 2017). To quantify changes in these indicators, appropriate metrics have been selected which detect and measure change in the indicator state from a temporal baseline (McQuatters-Gollop et al., 2019; Rombouts et al., 2019). As current indicator state is compared to this baseline to evaluate change, here we refer to this temporal baseline as a 'comparison period'.

This temporal comparison period can be selected for a series of years that are considered to best represent Good Environmental Status, so that deviations away from this period inherently imply the pelagic habitat is not in GES (Dickey-Collas et al., 2017; Scherer et al., 2016). Plankton communities, however, are highly dynamic, species rich, and are driven by a multitude of complex ecological processes. An initial role of indicators therefore, before the evaluation of GES, is in the detection of a change in plankton community state compared to background variability. A comparison period for pelagic habitat indicators needs to be suitable for providing an initial flag of change in pelagic habitat state. This flagging process can trigger subsequent investigations as to how that change in state relates to Good Environmental Status, including identifying the underlying causes of change, and any implications for management.

An inherent challenge in the development of pelagic habitat indicators therefore, is the selection of an appropriate temporal scale from which to compare current indicator state, i.e. whether to compare current indicator state to the full extent of a multi-decadal time series, or just a recent period. For example, it may be important to account for ‘shifting baselines syndrome’ in ecosystem state that has been identified within other areas of marine conservation (McClenachan et al., 2015; Pauly, 1995; Thurstan et al., 2015) . This is the phenomenon where neglecting past changes obscures the magnitude of change or variability in ecosystem components. Here, plankton data from the beginning of long-term time-series provide a possibility for setting a comparison period for pelagic habitat assessments that minimises shifting baselines syndrome. For example, Wasmund (2017) used historical plankton data to define a threshold value for the ratio for the diatom/dinoflagellate index, an indicator of plankton community structure used in assessments of the Baltic Sea, arguing that using pre-eutrophication period from the first half of the 20th century in the Baltic Sea provides a relatively pristine period for comparison. Furthermore, it is well understood that multi-decadal data are required for detecting climate change signals. For example, a well-documented climate change-driven regime shift occurred in the late 1980s in the North Sea, associated with a fundamental restructuring of the food-web (Reid et al., 2015). Including data from before, as well as after, this regime shift in the comparison period would be required to account for impacts of this regime shift in the assessment of current biodiversity indicator status. This requirement further supports the use of long temporal scales when establishing whether the current indicator state represents a changed or perturbed pelagic habitat (Giron-Nava et al., 2017; Henson et al., 2010).

On the other hand, there are arguments against the use of including historic data, e.g. from the beginning of a long multidecadal time-series, in comparison periods, and instead establishing a comparison period using contemporary data. Firstly, plankton communities are naturally variable at seasonal, inter-annual and multi-decadal time-scales. The biodiversity of a given ecological community can be seen as having a temporal component, and turnover in a community occurs regardless of human pressures, meaning a degree of multidecadal change is to be expected (Magurran et al., 2010). Secondly, 'legacy' effects, where the state of an ecosystem at a given point in time (in this case an MSFD assessment period) is representative of previous accumulated human pressures, as well as the pressures for the period that is being assessed (O'Higgins et al., 2014). A balance must be drawn as to whether management is focused on contemporary pressures occurring in the current assessment cycle, or on the reduction and remediation of longer term legacy effects. Lastly, and arguably the largest challenge for pelagic habitats, is that climate change is outside the scope of drivers managed under the MSFD, and climate change can obscure the response of plankton communities to management measures aimed at direct localised pressures. Duarte et al. (2009) for example show that reduction in nutrient levels did not result in a return of a eutrophic coastal system to a pristine reference status, due to underlying environmental changes. Climate change is instead categorised as a 'prevailing condition' by the Directive, and state changes caused by climate change are not legislatively required to lead to a management response (McQuatters-Gollop, 2012). These factors together therefore call into question the use of assessing indicators for certain policy needs over long, multidecadal time-series. For example, is detecting the impacts of a regime shift in the 1980s relevant for current management? Would it instead be more useful to assess indicator change over a shorter, more contemporary time-scale?

Given these questions, much attention has been drawn to the temporal scale of indicator reporting within the Marine Strategy Framework Directive. A recent analysis by Machado et al. (2019) highlighted a lack of consensus on appropriate temporal scale by Member States in their MSFD reporting, leading to varied time-scales and a lack of comparability across indicators and regions. They also advise against the use of opportunistic historical data in reporting indicator trends, and advocate for more structured harmonisation of temporal scales. It is important therefore, to understand how temporal scale influences the outcome of indicator assessments to consolidate an appropriate temporal scale for reporting between indicators and assessment regions. It is also important to understand how different temporal scales may give different types of information to policy for making management decisions.

Here we use two plankton indicator metrics developed at the OSPAR level (the regional seas convention for the North-East Atlantic) to test how different time scale lengths affect the assessment of an indicator. Underlying these tests is understanding whether including data from further in the past in the comparison period increases the chances of detecting a state change in the assessment period (because for example, data from different climate regimes are compared), or whether including this data decreases the ability of detecting state change because more variability is encompassed within the comparison period. The first indicator metric aggregates plankton taxonomic data into broad functional groups, termed 'lifeforms', and compares the current balance of key plankton functional groups in the system to prior time-points in a time-series (McQuatters-Gollop et al., 2019). This metric forms the assessment of the OSPAR PH1 indicator 'Change in Phytoplankton and Zooplankton Communities' (OSPAR, 2017a). The second indicator metric partitions the total variability in a time-series into the 'Local Contributions' of individual time-points, to detect whether the current plankton community composition is or anomalous, compared to that of the wider time-series. This 'Local Contribution to Beta Diversity (LCBD)' metric contributes to a multi-metric index for assessing the OSPAR indicator PH3 'Changes in plankton diversity' (Budria et al., 2017; OSPAR, 2017b; Rombouts et al., 2019). Both indicators are reliant on comparison to previous data in a time-series, and therefore the outcomes of assessing these indicators are inherently influenced by the temporal scale of the comparison period. We therefore aim to understand the influence of short, medium and long temporal scales of indicator assessment.

2 Materials and Methods

2.1 Plankton community data

Plankton community data were obtained from the Continuous Plankton Recorder (CPR) survey (DOI: 10.7487/2019.98.1.1181). The CPR survey has been collecting samples in the North Sea on a routine, consistent basis since 1958, creating a fully comparable multi-decadal time-series. CPRs consist of a filtering mechanism housed in an external body that is towed behind ships of opportunity at a depth of approximately 7-10m, with each sample representing approximately 10 nautical miles (18.5km) of tow, and approximately 3m^3 of sea (Batten et al., 2003). Both phytoplankton and zooplankton data are then identified and enumerated on a semi-quantitative scale (Richardson et al., 2006). Focusing on the North Sea as a case study for indicator assessment, samples were extracted from a 'northern North Sea' and a 'southern North Sea' bounding box (Figure 1). Only taxa enumerated consistently throughout the time-series were included in the analysis.

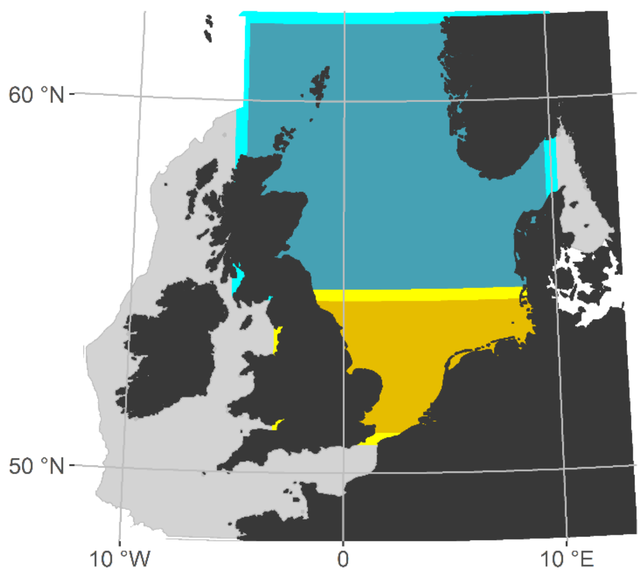

Figure 1. Northern North Sea (blue), and southern North Sea (yellow) study regions.

2.2 Indicator metrics

2.2.1 Plankton lifeform index

An indicator based on functional traits has been selected for assessing changes in plankton community structure under the MSFD (McQuatters-Gollop et al., 2019). The indicator is based on grouping taxa into their respective ‘lifeforms’ based on shared functional traits. Lifeforms are groups of taxa that play the same functional role within an ecosystem (Tett et al., 2013) and are analogous to functional groups. As ecosystems experience change and are subjected to pressures, the relative proportions and ratios of different life forms can change. Monitoring the relative abundance of key lifeforms can therefore help assess change in ecosystem state. The method of aggregating individual taxa into lifeforms is outlined in McQuatters-Gollop et al. (2019). Here we use five lifeform pairs included in the OSPAR Intermediate Assessment of 2017 (2017a): Diatoms/Dinoflagellates, Phytoplankton/ Non-carnivorous zooplankton, Pelagic/Tychopelagic diatoms, Small/Large copepods, and Holoplankton/Meroplankton.

The metric currently employed by OSPAR to quantify changes in the lifeform indicator is the ‘Plankton Index’, and is based around a ‘state-space’ approach (Tett et al., 2008). This approach involves selecting key lifeform pairs, based on their link to ecosystem structure and functioning, then plotting the abundance of the first lifeform for each month in a time series on the X axis, and the second lifeform on the Y axis (Tett et al., 2013). For example, in Figure 2 the abundance of diatoms is plotted on the X axis and the abundance of dinoflagellates on the Y axis, so that monthly plankton communities are plotted in ‘state-space’. As ratios of lifeforms vary naturally, e.g. seasonal variation, plotting multiple coordinates from months taken throughout a defined time period produces a ‘domain’ within the plot of ecosystem state. The current plankton community, within the period that is being assessed, is used to create this domain. We hereby refer to this period as the ‘assessment period’. Previous time periods (i.e. ‘comparison periods’) can be compared to this assessment period domain by overlaying the months for the previous time period in question. If these points fall within the domain, it suggests the current state within the assessment period does not represent a change. If however these points fall outside the domain, it suggests the current state within the assessment period is different to previous time periods. This change in state is calculated as the proportion of points falling within the domain, quantified as a standardized 'Plankton Index'. The lower the proportion of points falling inside the assessment period domain, the lower the Plankton Index value, and so the greater the change in state. In Figure 2, the assessment period represents a changed ecosystem state from the comparison period, revealing community change within the pelagic habitat (Tett et al., 2013).

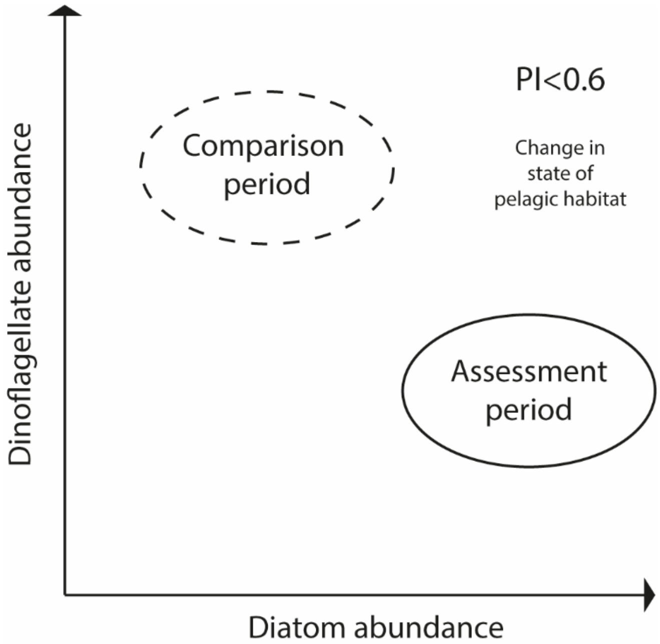

Figure 2. The Plankton Index approach. Data from the current assessment period is used to create a domain. The comparison period is subsequently overlain and the PI quantifies the proportion of points falling outside of the domain. Here, we use a PI threshold of 0.6 to distinguish a state change from underlying variability.

In this study, the total for each lifeform was calculated for each CPR sample in each of the two North Sea regions. These were then aggregated into annual means before being $\log_{10}$ (x+1) transformed. Months between 2013 and 2017 were used to create the assessment period domain for each lifeform pair for each region. This domain is calculated as an envelope that excludes the most extreme 10% of data points. The PI value is then calculated as the proportion of new points falling inside the domain, out of the total number of new points. To distinguish a state change from background variability, for this study we used a threshold of PI > 0.6 (i.e. fewer than 60% of points falling within the assessment period domain) to represent a state change.. The value of 0.6 was selected based on expert opinion, to represent a balance between sensitivity of the metric but allowing the distinguishing of change from background variability. As the selection of thresholds is a developing area, during future assessments this value may change based on quantitative criteria such as adjusting for multiple testing.

2.2.2 Local Contribution to Beta Diversity

This indicator metric identifies atypical or unique plankton community composition in a time-series, compared to other time-points (Legendre and Gauthier, 2014) (without reference as to whether this composition is ‘good’ or ‘bad’ in terms of environmental status). It is based on the concept that the total variability in community composition between points in a time-series can be viewed as the temporal ‘Beta Diversity’ of the time-series, analogous to the more classical use of Beta Diversity as a spatial concept. This total Beta Diversity can then be partitioned into the contribution each time-point makes to the total variability. Time-points with significant contributions to the total can be viewed as contributing disproportionately to total variability, and therefore are atypical, or unique, in community composition, accounting for taxa identity, richness and dominance structures. This method therefore allows the evaluation as to whether the current assessment period is atypical in plankton community composition compared to a comparison period of previous time-points in the time-series. In this way, the evaluation of the assessment period will depend on the length of time-series used as a comparison period.

To calculate the 'Local Contribution to Beta Diversity' (LCBD) metric on annual mean data, first 'Total Beta Diversity' of both phytoplankton and zooplankton time-series was calculated following Legendre and Cáceres (2013). Total Beta Diversity (BD_{Total}) under this method was calculated as the total variance of the year-by-species community data, so was calculated without reference to alpha and gamma diversity as in other metrics of Beta Diversity (Anderson et al., 2011). A matrix of squared deviations from species means was calculated for each year for each species, so that if the abundance of a particular species was the same in all years, the values for that species were zero in each year. The total of these squared deviations were then summed across the species-by-year abundance data (SS_{Total}). BD_{Total} was then calculated as ($SS_{Total}/(n-1)$), where n refers to the number of years.

For this study, the mean monthly abundances of each taxa were $\log_{10}(x+1)$ transformed, with any gaps in the monthly mean time-series filled through linear interpolation, before being further aggregated to annual means (Richardson et al., 2006). These annual means were then chord transformed prior to analysis to make the data suitable for Beta Diversity analysis and to avoid putting a large emphasis on rare species (Legendre and Borcard, 2018; Legendre and Gallagher, 2001). Total Beta Diversity was then partitioned into the contribution of each individual year to the BD_{Total}, so that each year had an associated LCBD value. LCBD indices were tested for significance through permutation testing.

To further interpret variation in the LCBD metric, we then identified the taxa that contribute the most to total community variability across the time-series. Here BD_{Total} was partitioned into the contribution each taxa makes, rather than each time-point makes as for LCBD. For each plankton community time-series, we calculated the 'Species Contributions to Beta Diversity (SCBD)' metric (Legendre et al., 2005) for each taxon, with taxa with high SCBD values showing the highest variation across the time-series, i.e. the highest contributions to BD_{Total}. All calculations and analyses of LCBD and SCBD were undertaken using the beta.div function in the R package 'adespatial' (Dray et al., 2016).

2.3 Temporal scale analysis

For this study, we used 2013-2017 as the focal period for an assessment, i.e. the policy aim is to characterise the plankton community within this period in relation to previous time periods. These are the latest5 years of the CPR time-series included in this study, and represent the period of time that would be assessed within the latest 6-yearly cycle of the MSFD implementation process. This current assessment period was then compared to three comparison periods of varying temporal scale. Firstly, a short-term comparison period going back to 2004 was used. This short-term comparison period represents the previous policy cycle to the assessment period, so is analogous to assessing whether there has been a state change since the last policy cycle. Secondly, a medium-term comparison period going back to 1990 was selected to represent a multi-decadal perspective, but post the1980s regime shift. Lastly, we used a long-term comparison period going back to 1958, which is the start of the consistent CPR time-series. This long-term period represents a multi-decadal perspective including the time periods before and after the 1980s regime shift.

The assessment period of 2013-2017 was assessed at these three temporal scales using each indicator metric. For the Plankton Index metric, the period 2013-2017 was used to create the assessment period domain, and then data between 2004 and 2012, 1990 and 2012, and 1958 and 2012, respectively, were overlaid and a Plankton Index value calculated. This analysis therefore covered both different discreet periods of time within the comparison period, and also different lengths of comparison period. For the LCBD metric, three time-series were created, 2004-2017, 1990-2017, and 1958-2017. The BD_{Total} was calculated for each time-series and the LCBD values for each year in each time-series calculated. These time-series of LCBD values were then used to evaluate whether the assessment period of 2013-2017 was assessed as atypical at each of the three temporal scales.

3 Results

3.1 The effect of temporal scale on the plankton lifeform index

Outputs of the Plankton Index for the five lifeform pairs included in this study are shown in Table 1. When using a PI threshold of 0.6 to establish whether there has been a change from the comparison period, the southern North Sea appears more stable in terms of plankton community change on the short-term scale compared to the northern North Sea, which experienced change in all lifeforms pairs apart from Pelagic/Tychopelagic diatoms during all three time-scales. Similarly, using the long-term comparison period, two of the lifeform pairs showed a change below the threshold in the southern North Sea, whereas all six lifeform pairs showed a change in the northern North Sea when including long-term data in the comparison period.

Table 1. Results of the Plankton Index for each lifeform pair in each region. PI<0.6 represents a state change.

Lifeform pair	**northern North Sea**			**southern North Sea**		
	Short-term (2004-2012)	Medium-term (1990-2012)	Long-term (1958-2012)	Short-term (2004-2012)	Medium-term (1990-2012)	Long-term (1958-2012)
Diatoms/Dinoflagellates	**0.54**	**0.57**	**0.54**	0.64	0.64	**0.53**
Pelagic/Tychopelagic diatoms	0.62	**0.58**	**0.55**	0.72	0.69	0.62
Phytoplankton/ Non-carnivorous zooplankton	**0.52**	**0.58**	**0.56**	0.69	0.69	0.63
Large/Small copepods	**0.52**	**0.48**	**0.37**	0.8	0.7	0.62
Holoplankton/Meroplankton	**0.59**	**0.46**	**0.34**	0.62	**0.55**	**0.44**

There are also differences between lifeform pairs in terms of their assessment outcomes at different temporal scales. There is a general trend that as the temporal scale of the comparison period increases (i.e. data from further back in time is included in the comparison period), the PI value lowers, therefore indicating greater change. For example, the Holoplankton/ Meroplankton pair in the northern North Sea showed a change across all temporal scales, with this change getting stronger (increasingly smaller PI values) as the temporal scale of the comparison period increased (Figure 3A). This pattern suggests this lifeform pair shows a clear trajectory of change over time. A similar pattern occurs for the Large/Small copepod pair in the northern North Sea. In contrast, Large/Small copepods in the southern North Sea showed stability across all three temporal scales, suggesting that little directional change has occurred in this lifeform pair in this area over multi-decadal scales (Figure 3B). Stability in the southern North Sea across all three temporal scales is also shown in Pelagic/Tychopelagic diatoms, and Phytoplankton/Non-carnivorous zooplankton.

Some lifeform pairs however, show different results depending on temporal scale when using 0.6 as a threshold. In the southern North Sea for example, diatoms and dinoflagellates show stability over the short and medium time scales, but change over the longer time-scale (Figure 3C). This pattern suggests that a large change in this lifeform pair in the southern North Sea occurred before 1990, after which it appears more stable.

3.2 The effect of temporal scale on the LCBD indicator metric

Results from the analysis of temporal scale on the LCBD metric are shown in Table 2. Similarly to the PI outputs, results vary between short-term, medium-term and long-term time-scales. Results vary in two main ways. Firstly, the years that are calculated as having significant Local Contributions to Beta Diversity vary. For example, in the southern North Sea, 2017 was assessed as having a significant LCBD for phytoplankton when looking at the short time-scale (Figure 4B). When including data before 2004, however, 2017 was no longer assessed as significant. Instead, when looking at the longest time-scale an extended period during the late 1970s and early 1980s was assessed as significant. When looking at the longest time-frame, therefore, most of the overall time-series variability (BD_{Total}) is driven by this period, rather than the current assessment period. Increasing temporal scale in this context therefore decreases the likelihood of assessing the current assessment period as anomalous, as more variability is encompassed in the comparison period than in the assessment period. This contrasts to the northern North Sea (Figure 4A), where the years 2016 and 2017 were assessed as significant over the long temporal scale, but not under the short or medium-term scales.

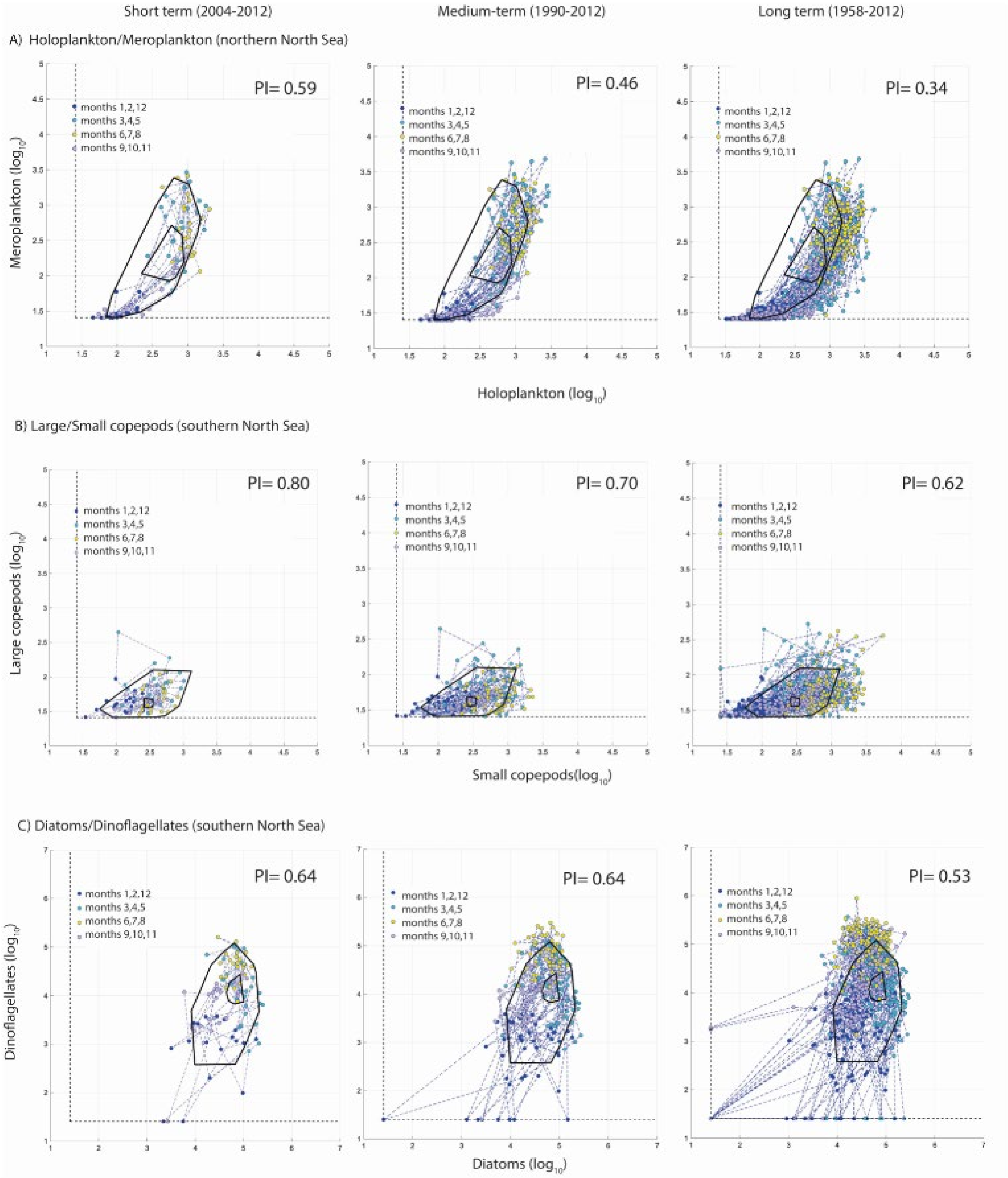

Figure 3. Visualisation of the Plankton Index using different temporal scales of comparison periods. A) Holoplankton/Meroplankton in the northern North Sea. An example of a lifeform pair showing change over all three temporal scales. B) Large/Small copepods in the southern North Sea. An example of a lifeform pair showing stability over all three temporal scales. C) Diatoms/Dinoflagellates in southern North Sea. An example of a lifeform pair showing stability on the short and medium time-scales, but change over the long-term time-scales.

Table 2. Outputs of the LCBD metric at different temporal scales. For each community (phytoplankton/zooplankton) in each region (northern/southern North Sea), the years with significant LCBD metrics are shown, with years in the assessment period (2013-2017) highlighted in bold. For each community, the 'top 3' species with the largest SCBD values are listed.

	Short-term (2004-2017)		Medium-term (1990-2017)		Long-term (1958-2017)	
Plankton community	Significant LCBD years	Top three SCBD	Significant LCBD years	Top three SCBD	Significant LCBD years	Top three SCBD
Phytoplankton (northern North Sea)	2004	***Nitzschia spp. (unidentified)*** *Thalassionema nitzschioides* *Corethron hystrix*	1992,1996,2008	***Nitzschia spp. (unidentified)*** *Ceratium furca* *Thalassiothrix longissima*	1972,1979,1980, 2007,2008,2009, **2016,2017**	***Ceratium macroceros*** *Ceratium furca* *Prorocentrum spp. ('Exuviaella' type)*
Phytoplankton (southern North Sea)	2004, 2011, **2017**	***Ceratium macroceros*** *Nitzschia spp. (unidentified)* *Thalassionema nitzschioides*	1990,1992	***Ceratium furca*** *Rhaphoneis amphiceros* *Ceratium macroceros*	1958, 1973,1978,1979, 1980,1982,1990	***Ceratium macroceros*** *Ceratium furca* *Thalassionema nitzschioides*
Zooplankton (northern North Sea)	None	***Penilia avirostris*** Appendicularia *Centropages spp. (Unidentified)*	1991,2009	**Bivalve larvae** *Penilia avirostris* *Para-Pseudocalanus spp.*	1961,1965,1978, 1980,1981,2007	***Calanus finmarchicus*** *Centropages typicus* *Echinoderm larvae*
Zooplankton (southern North Sea)	2007	**Appendicularia** *Penilia avirostris* *Centropages hamatus*	1990,1991,2007	***Centropages spp. (Unidentified)*** *Penilia avirostris* Echinoderm larvae	1958,1979,1982	***Centropages typicus*** *Oithona spp.* Appendicularia

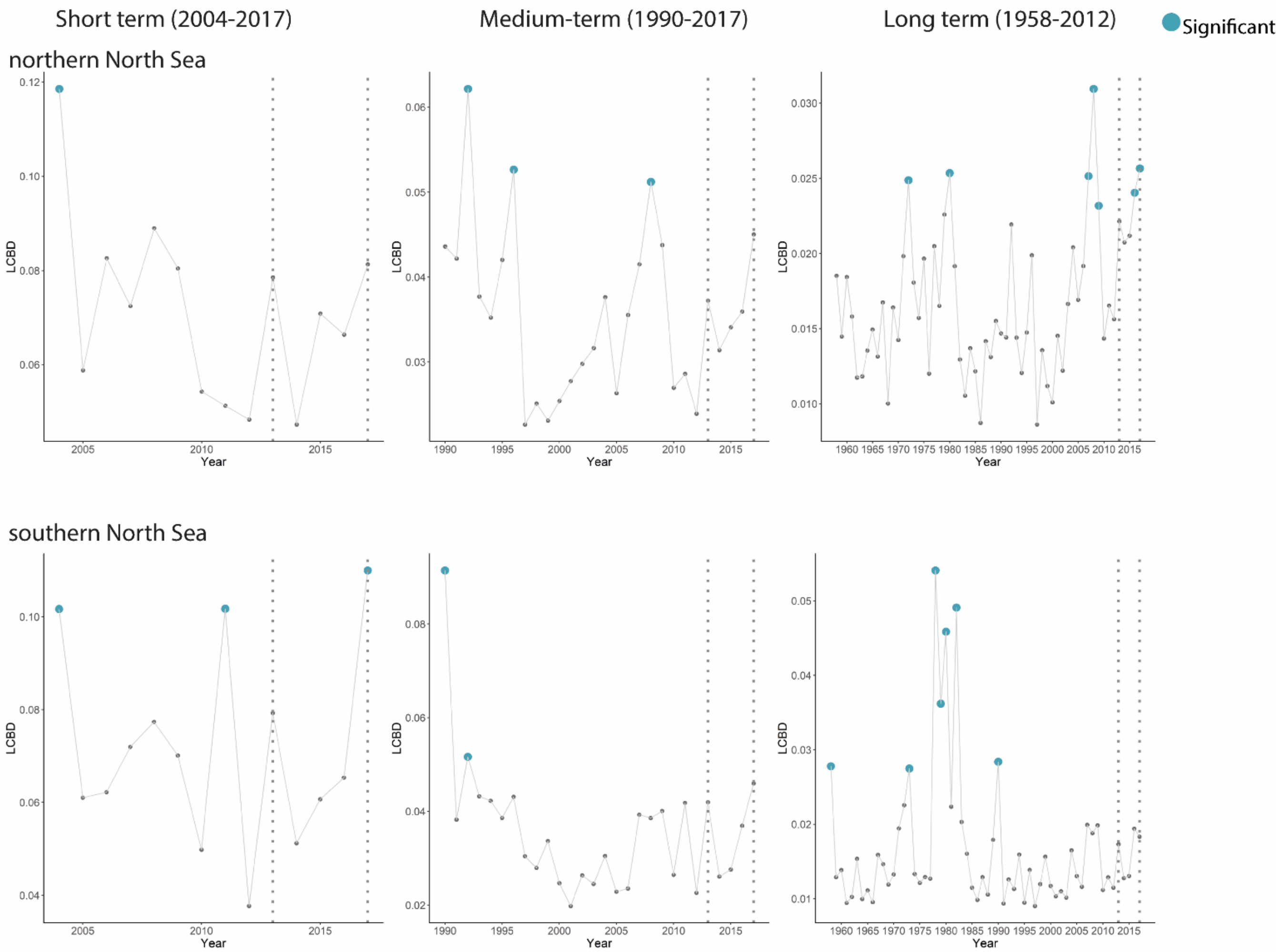

Figure 4. LCBD values for phytoplankton communities in the Northern and southern North Sea. Large blue dots indicate years with significant LCBD values at each time-scale. The assessment period of 2013-2017 is shown with vertical dotted lines in each plot.

As well as different years being assessed as significant, different taxa were identified as the main drivers of community variability at different time-scales (i.e., have the highest SCBD values). For example, in the northern North Sea region for zooplankton (Figure 5), the invasive cladoceran *Penilia avirostris* has the highest SCBD in the short-term, although no years had significant LCBD values at this time-scale in this region. At the medium time-scale, Bivalve larvae contributed the most to community composition variability, but at the long-term scale, *Calanus finmarchicus* contributed the highest to variability. This in turn affects the years that are assessed as having significant LCBD values (Figure 4). The years 1991 and 2009 are assessed as significant over the medium-term, which frame a period of rapid decline in the abundance of Bivalve larvae, moving from a positive to a negative abundance anomaly. When looking at the long-time-scale, the years 1980 and 1982, as well as 2007 are assessed as significant, which frame a period of rapid decline in the abundance of *Calanus finmarchcus*. When looking at the short-term, these taxa are relatively stable in abundance and do not contribute as highly to the total Beta Diversity (BD_{Total}). In the southern North Sea for zooplankton, *Centropages typicus* contributed highly to BD_{Total} over the longest time-scale, but unidentified *Centropages* spp. and Appendicularia contributed the most over the medium and short time-scale, respectively.

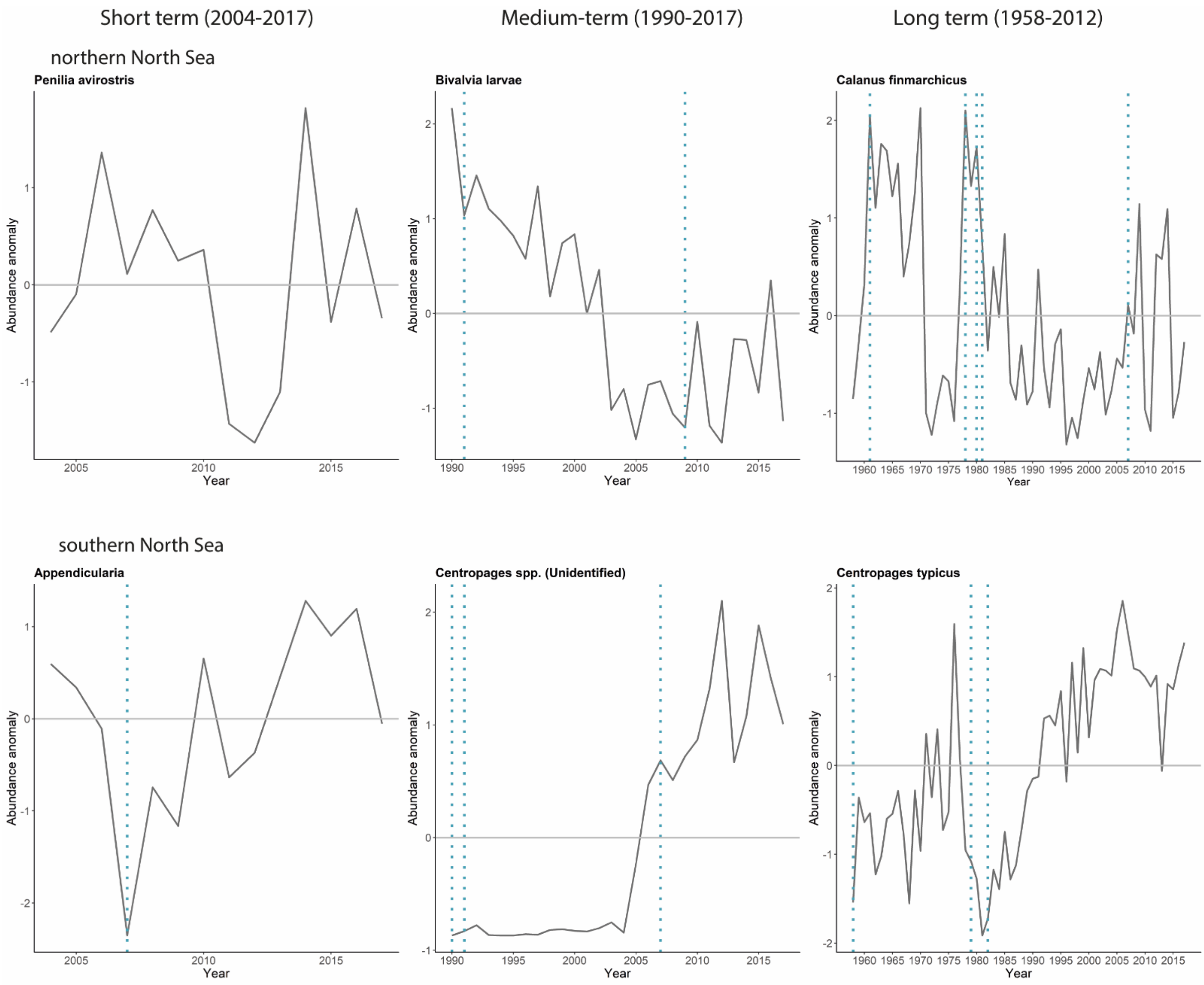

Figure 5. The taxa with the highest 'Species Contribution to Beta Diversity (SCBD)' values for zooplankton at short, medium and long time scales. Abundance expressed as standardized anomalies of long term mean. For comparison, for each area and time scale the years with significant 'Local Contribution to Beta Diversity (LCBD) values are shown with a blue dotted line.

4 Discussion

Distinguishing ecologically-meaningful change in plankton communities from background variability is a key challenge facing the formal assessment of pelagic habitats under policy drivers. However, detection and interpretation of change depends on the years selected for the comparison period, and here we have highlighted that the temporal scale of the comparison period affects the outcome of indicator assessments. For example, the Plankton Index based on lifeform pairs generally reveals greater change when including data from further back in time. This supports the concept that increasing the temporal scale of the comparison period increases the detection of change, because data from historic environmental conditions are included.

This conclusion does not consistently extend to the LCBD indicator metric, however. For example, the LCBD indices for phytoplankton in the southern North Sea area revealed that 2017 was anomalous on the short time-scales, but not on the medium or long-term time-scalesAlthough the two indicators display non-consistent patterns when assessed over increasing temporal scales, they provide different, yet complementary ecological information. When assessing over the shorter time scales therefore, there may be years within the assessment period identified as anomalous in species-level community composition, even though overall the assessment period doesn't represent a fundamental change in functional group structure.

Most of the long-term time-series variability for southern North Sea phytoplankton was driven by an anomalous period in the late 1970s, indicated by a period of consistently significant LCBD indices. This anomalous period in the CPR time series has previously been associated with a pulse of cold, low salinity water entering the North Sea causing a rapid decrease in SST and salinity (Dickson et al., 1988; Edwards et al., 2002). This 'Great Salinity anomaly' caused an associated shift in phytoplankton community composition, most notably a sharp population crash of *Ceratium macroceros,* which here had the highest SCBD value at the long time-scale. Such extreme anomalies in community composition when looking at the long-temporal scale can mean that any shorter-term variability is not assessed as significant. In this specific case therefore, increasing the temporal scale over which the indicator is calculated decreases the likelihood that the current assessment period represents a change.

A large cause of the underlying variability in assessment outcomes at different temporal scales is the regime shift that occurred in the 1980s; including data from before the regime shift affects the conclusion of whether the current assessment period represents a change. For example, the PI for Diatoms/Dinoflagellates in the southern North Sea region was stable over the short- and medium-term time-scales, but fell below the 0.6 threshold when including pre-regime shift data, indicating a state change in the community over a long-multidecadal time-scale. This multidecadal pattern in diatoms and dinoflagellates indicates a shift in trophic pathways within the pelagic ecosystem. Similarly, when looking at the Species Contributions to Beta Diversity, long-term variability in southern North Sea zooplankton was largely driven by *Centropages typicus*, which showed a rapid increase in abundance between 1982 and 2005. Both these years had significant LCBD values, ‘framing’ this increase in *C. typicus*. *C. typicus* did not have a large contribution to overall variation in community composition over the short-time-scale, however, suggesting its abundance was stable over this short temporal scale. The tendency for significant LCBD indices to ‘frame’ a specific event as found here was also found by who showed that LCBD values for mollusc assemblages before nuclear testing events were significant over a long-term-time-series indicating that the intervention of nuclear testing led to the establishment of a community largely different to what it had previously been. This highlights the importance of hindsight for this indicator metric; a given year can become significant once more data are added to the time-series.

When a long-term time-series experience a major hydrographic change, such as a regime shift, the question therefore becomes ‘Do we select a comparison period representing ‘new conditions’ or do we use the whole time-series as a comparison?’. Given the large influence of climate change, which is outside the scope of the MSFD, on pelagic habitat biodiversity indicators, it may be appropriate to first use contemporary data within the current climate regime as a comparison period. For the assessment of plankton lifeforms for example, this would involve calculating the Plankton Index between the current assessment period and contemporary data (such as the short- or medium-time-scale periods used here), rather than comparing all the way back to 1958.

The importance of understanding the influence of changing oceanographic and climatic conditions on biodiversity indicators, however, is increasingly being recognised as important for developing effective marine strategies (Bedford et al., 2018). This understanding provides a broader perspective of changing marine ecosystems upon which directly manageable pressures are superimposed. Crucially, therefore, after assessing over short-temporal scales, long-temporal scale data can then be used to provide context to the assessment, and inform on multi-decadal changes including any signals of climate change. By using long temporal scale data in this additional, contextual way, the assessment process can adapt to ongoing environmental change, whilst also avoiding shifting baseline syndrome by not losing important information on the influence of prevailing conditions (Figure 6).

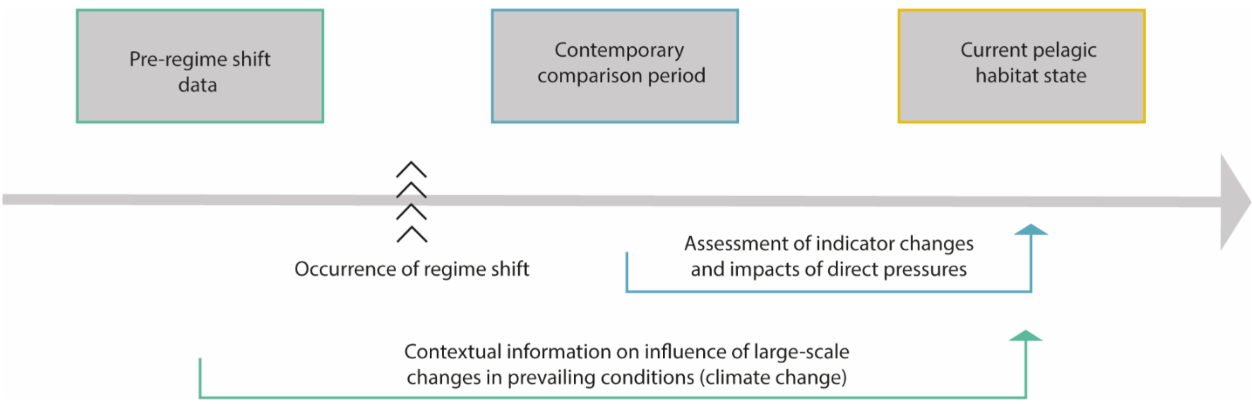

Figure 6. Suggested incorporation of climate regimes into the pelagic habitat assessment process in the North Sea. Contemporary data can be used first as the comparison period for assessments, but, crucially, long temporal scale data should be used as 'contextual data' to inform on the influence of changing prevailing conditions, helping to avoid shifting baselines syndrome.

The LCBD metric is a key example of an indicator that provides different types of information when assessed over different temporal scales. Whereas over short time-scales the LCBD indicator may reveal short-term population changes and anomalous phytoplankton blooms (Rombouts et al., 2019), we have highlighted here that over long temporal scales it can reflect large-scale ocean climate anomalies and climate driven shifts. Similarly, identifying the species contributing the most to total compositional variability at long time-scales gives insight to large-scale climate-driven shifts. For example, the copepod species *Calanus finmarchicus* had the highest zooplankton SCBD value in the northern North Sea over the long-temporal scale, indicating its long-term importance to the community. *Calanus finmarchicus* is a keystone species in the North Atlantic food-web, and has undergone a much-documented decline in the North Sea in response to warming, with ramifications for higher trophic levels (Helaouët and Beaugrand, 2007).

4.1 Conclusion

Where resources and time-series length allow, assessing indicators over multiple temporal scales provides different scales of information to policy assessments; from detecting detailed changes within the current management cycle, to providing broad-scale multi-decadal context to assessments. Selection of appropriate temporal scales is therefore a key example of the importance of co-production and dialogue between scientists and policy-makers during the development of biodiversity indicators.

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